Article

The Value of Genetic Improvement Evaluated Using a Whole of Enterprise Market Model

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Abstract: The net return from milk to the producers is defined as the aggregate market income from dairy products, after deducting all processing and marketing costs. The way to distribute this net return is through the payment system, which is usually based on multiple components, mainly with a reward for fat and protein and, in the case of the New Zealand dairy industry, a penalty for milk volume. Traditionally, the value of genetic improvement is evaluated using selection index theory assuming that there is an unlimited market where all dairy products can be sold in unlimited amounts at a fixed price and therefore economic values for fat and protein are assumed to be independent of demand. The objective of this study was to estimate the value of continuous genetic improvement evaluated using a model encompassing all the dairy producers in the industry where prices of the dairy products were determined by product specific supply-demand curves. Over 10 years of genetic improvement, the present value of the benefit (10% discount rate) was estimated to be $123,000 per farm. The corresponding benefit when the markets were assumed to have fixed commodity prices was $183,000 per farm. The model revealed that systematic genetic gains had a finite duration during which incremental benefits progressively declined and would be exhausted eventually.

Keywords: genetic improvement; dairy enterprise; whole of market; pure competition

1. Introduction

Whole-farm models have been developed to simulate productivity and profitability of grazing systems in New Zealand; the Whole-Farm Model [1], e-Dairy [2], and Farmax Dairy Pro [3]. Other farm models have been developed in other countries including the Moorepark Dairy System Model developed in Ireland [4], the DairyWise model developed in the Netherlands [5] and a dairy farm model for Australian grazing systems [6]. In these models, profitability indicators were calculated based on the milk payment dictated by the dairy companies marketing the dairy products. The milk payment formula used to reward suppliers for their milk production has a limited fundamental basis and is essentially an agreement between suppliers and their milk marketing company.

Consequently, in a well-integrated industry, the net return from milk to the producers is defined as the aggregate market income from dairy products, after deducting all processing and marketing costs [7]. The way to distribute this net return is through the payment system, which is usually based on multiple components, mainly with a reward for fat and protein and a penalty for milk volume. However, in an industry such as in New Zealand, the milk is processed into a diversity of products ranging widely in composition that necessitate some arbitrariness in allocations between the constituents of the payment formula.

Most modern dairy industries include a breeding program embedded within the milk production system and the processing sector. The breeding objective is then defined as the breeding for cows that are expected to be more profitable for the farmers for future

production, environment, and economic circumstances [8]. The selection of cows and bulls is based on a selection index that uses estimated breeding values or genomic breeding values for economically relevant cow traits, each weighted by the economic value of the trait. It is expected that the overall population of cows will undergo genetic changes i.e., improvement, for the traits in accordance with their individual heritability, reliability of estimated breeding values and relative economic value given in the selection index. In the case of the New Zealand dairy industry, cows and bulls are selected based on a selection index called the Breeding Worth, which includes lactation yields of milk, fat and protein, mature cow live weight, somatic cell count, cow fertility, gestation length, functional survival, body condition score and udder overall.

Responses to selection for individual traits and breeding worth for different selection schemes and using crossbreeding systems can be estimated using selection index theory [9] as illustrated in [10]. To the authors' knowledge, there is not a single report in the literature that makes a detailed estimate of the value of genetic gain for all the farmers in the industry and more especially relative to the value of dairy production in a competitive market. The objective was to assess the value of sustained projected genetic changes for milk, fat, protein, lactose and live weight across the New Zealand dairy industry and to examine its consequences. The implications of these expected genetic gains were examined using an overarching whole of market model.

2. Materials and Methods

2.1. Cost Structure

Lopez-Villalobos et al. [11] proposed a pure competition model that simulated the production of milk, fat, protein and lactose of the national herd, the processing of milk into dairy products and market sales of these products at prices determined according to price-supply curves (a summary of the model is shown in Figure A1 of Appendix A). The model was updated to embody 2017-18 costs and prices. Farm costs (Table 1) were obtained to reflect an average dairy farm in New Zealand [12].

Table 1. Partitioning of farm costs into cow and hectare bases, and fixed costs [1].

Cost Component	Total Farm NZD/(year)	Basis for Split of Each Code (%)		Allocated Costs NZD/(year)	
		Per ha	Per Cow	For Pasture Production	For Herd Operation
Wages	106,634	15	85	15,995	90,639
Animal health	37,160	10	90	3716	33,444
Breeding	25,851	5	95	1293	24,558
Supplementary feed	151,873	15	85	22781	129,092
Grazing	58,164	10	90	5816	52,348
Support block	11,310	10	90	1131	10,179
Fertilizer	77,552	80	20	62042	15,510
Irrigation	8078	90	10	7271	808
Regrassing	12,925	85	15	10987	1939
Farm dairy	9694	25	75	2424	7271
Electricity	17,772	20	80	3554	14,218
Weeds and pests	6463	90	10	5816	646
Vehicles and fuel	32,313	35	65	11,310	21,004
Repairs & maintenance	63,011	50	50	31,506	31,506
Freight	8078	0	100	0	8078
Administration	19,388	50	50	9694	9694
Insurance	12,925	70	30	9048	3878
Accident Compensation Levy	3231	100	0	3231	0
Local authority rates	17,772	100	0	17,772	0
Labour adjustments	64,627	50	50	32,313	32,313
Depreciation	67,858	55	45	37,322	30,536
Other adjustments	19,388	100	0	19,388	0
Interest on debt	150,000	60	40	90,000	60,000
Total	982,070			404,409	577,661
				$2661/ha	$1542/cow

[1] PERCENTAGE splits as published by Beca [13].

The on-farm costs were partitioned into a set that was independent of the herd size i.e., costs that determined the cost of the feed, and costs that varied in proportion to the size of the herd. The assessment of the farm costs was revised into fixed costs (essentially feed costs) and variable costs that varied according to the size of the herd according to the percentage splits published by Beca [13].

2.2. Production Factors

At the base year (2017), the average national herd (431 cows/herd) was assumed to have a productivity per lactation of 4284 kg milk yield, 206.3 kg fat, 167.4 kg protein (comprising 135.9 kg casein and 31.5 kg whey protein) and 204.1 kg lactose, and 464.4 kg live weight. At the time of analysis, 2017 was the most recent year where a full data set was available for all national production and associated genetic gain data. The model remains valid irrespective of year.

These values reflected a mixed breed population comprising 48.5% Holstein-Friesian × Jersey crossbreds, 33.1% Holstein-Friesian, 8.6% Jersey, and 9.8% other [14]. The average farm size was 153 ha [15] and produced 14.5 t/ha/year of pasture dry matter with a metabolizable energy content of 11 MJ/kg dry matter. Overall, 80% of the pasture dry matter was utilized. For this study, there were 11,539 herds in the New Zealand dairy industry [14].

Table 2 shows the age structure of the national herd and the age adjustment factors for productivity. The age adjustment factors were used to calculate the expected phenotypic performance of a cow according to her age. For example, a two-year old cow in her first lactation produced 75% of a mature fifth-year old cow in her fourth lactation.

Table 2. Age structure of the herd, survival rate and age adjustment factor for milk component yield.

	Age Class, Year										
	0	1	2	3	4	5	6	7	8	9	≥10
Percentage of the of the herd	16.9	15.6	13.9	12.1	10.3	8.7	7.1	5.6	4.4	3.3	2.2
Percentage of the milking cows			20.6	17.9	15.2	12.8	10.5	8.4	6.5	4.8	3.3
Surviving rate (%)	92	89	87	85	84	82	80	78	74	68	0
Age adjustment factor [1] (%)	0	0	75	87	95	100	100	100	100	97	92

[1] The age adjustment factors were used to calculate the expected phenotypic perfor-mance of a cow according to her age.

The metabolizable energy required of the whole herd (over the 11 age classes) was calculated by summing the separate metabolizable energy requirements for maintenance, growth, pregnancy, and lactation according to Agricultural and Food Research Council [15] methodology. Given the amount of metabolizable energy available from 1 ha of pasture and a contribution from supplementary feed, the stocking rate was determined from the ratio of metabolizable energy available per ha (MJ/ha) divided by the energy required per cow (MJ/cow). The overall stocking rate for the base national herd was 2.465 cow/ha, and given the farm size and number of farms, the total land area of the industry was 1,753,928 ha. With the base herd stocking rate and farm size, the number of cows in the herd was calculated and from the cost relationships in Table 1, the associated cow cost was $2661/cow per year and the feed cost was $183.5/ton DM.

Compared to the 2005 genetic base established for the national genetic evaluation, Table 3 presents the average breeding values of cows born between 2014 and 2018 for lactation yields of milk, fat and protein and live weight by birth year of the national New Zealand herd published by DairyNZ [16–19]. The average breeding values in Table 3 are based on the year the animal is born. It takes another two years for the heifer to reach its first lactation and perhaps another year to obtain a more reliable estimate of the cow's productivity. Another year lapses while the data are collected, analyzed and made available for publication. As a result, the base herd productivity was aligned with the latest estimate of the average rate of herd genetic improvement across the national herd of milking cows.

Table 3. Average breeding values for lactation yields of milk, fat and protein and live weight by birth year of cows in the national New Zealand herd.

Year Born	Milk (kg)	Fat (kg)	Protein (kg)	Live Weight (kg)
2014	185.5	9.4	10.2	5.5
2015	223.2	10.9	11.8	7.9
2016	208.5	10.5	11.9	7.4
2017	284.8	14.6	16.2	8.7
2018	299.0	15.5	17.3	7.7

2.3. Herd Genetic Gains

The expected annual genetic improvement trends were estimated as the slopes of the regression lines of breeding values for the different traits on year born and were 28.84 kg milk, 1.86 kg fat, 1.77 kg protein and 0.52 kg live weight from these data.

Once the total herd size in the base year (2017 and denoted as year 0) was obtained, the quantity of milk was calculated, and the total farm income was determined after optimization of the product mix to maximize the return from the milk produced. (Appendix A shows a snapshot of the progression of the calculations once the stocking rate had been determined). For the following year e.g., year 1, the average genetic performance of the national herd was increased by the expected annual genetic gain, noted above. The stocking rate was adjusted to maintain the balance between the metabolizable energy supplied by the pasture and supplements and the metabolizable energy requirements for all the animals in the herd. From the recalculated stocking rate, the herd size was recalculated, and the farm costs determined from the revised herd size. The milk produced by the 11,539 herds was converted into a re-optimized product mix of commodities and associated set of commodity prices to yield the farm income. The benefit was the difference between the income and farm costs. In parallel, the benefit was calculated using the fixed prices from the year 0 case. This procedure was repeated with further annual increases in genetic gain across the herds for each of the years 2 to 10. The benefit series (fixed price and dynamic pricing) were also compared by using an annual compounding discount factor of 10%.

2.4. Market Scenarios

Two market scenarios were evaluated; an unlimited market where all dairy products can be sold at the same price of the base year (fixed prices, as noted above), and a volume-price sensitive market where prices of the dairy products are determined by supply-demand curves in Figure 1.

The demand curves for the price-quantity relationships for the dairy commodities were determined using the historic data in the archive of Global Dairy Trade [20]. The curves are downwards sloping convex, in line with typical commodity demand curves. Since 2000 and 2018, the New Zealand dairy industry has seen a major increase in the production of infant formula. Five or six companies now have facilities wholly or partly dedicated to the production of infant formula and this earned NZD 1,200,000,000 in 2018 [21]. Since infant formula is produced almost entirely in cans and branded for retail sale, this production was treated as a fixed quantity (92,000 ton/year) and a fixed price (USD 8900/ton) i.e., it did not have a sloping demand curve as it was not a freely tradable international commodity. Processing costs for converting the milk into the various commodities were updated using price indices published by StatsNZ [22].
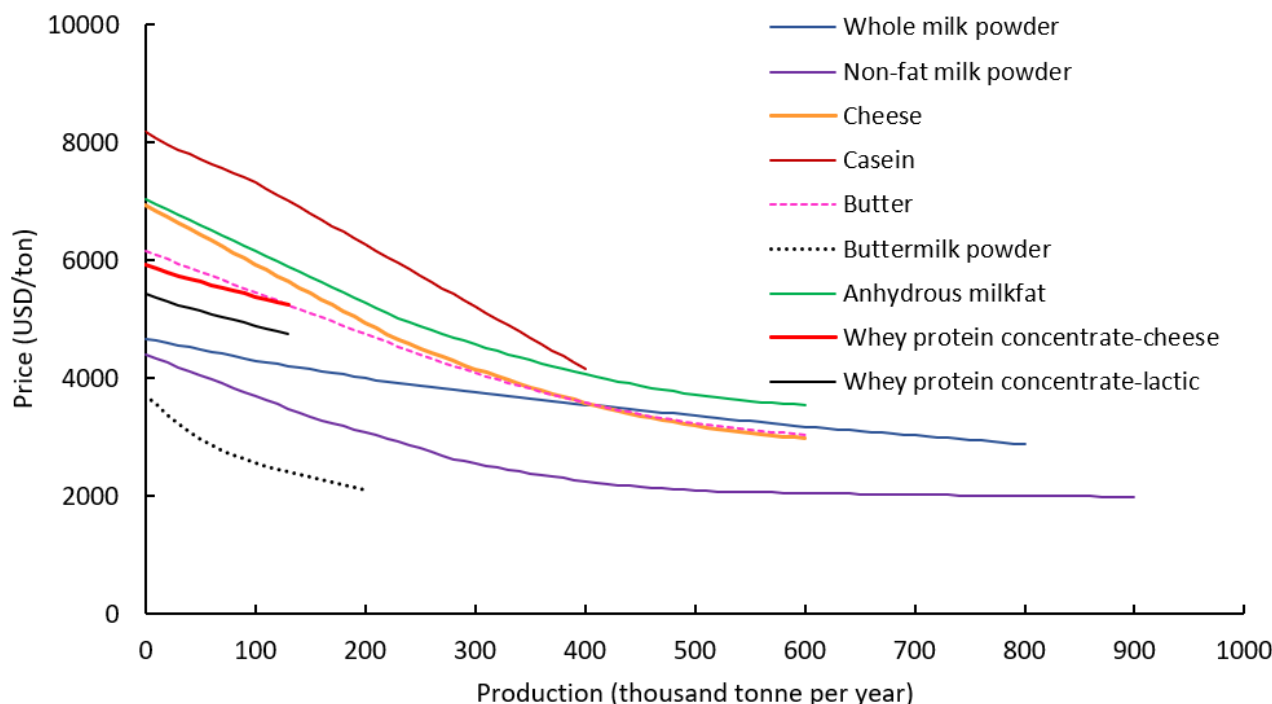
Figure 1. Price curves for the dairy commodities in a finite market for dairy products.

3. Results

Table 4 shows the expected live weight and production per cow per year of milk, fat, protein and lactose and reduction in stocking rate assuming the genetic gains for the traits obtained from Table 2.

Table 4. Effect of annual genetic improvement for lactation yields of milk, fat and protein and cow live weight on discounted and undiscounted industry benefit assuming fixed (unlimited market) and variable (market volume sensitive) prices of dairy products.

	Production Per Cow (kg/year)						Industry Benefit (NZ$ million/year)			
Year	Milk	Fat	Protein	Lactose	Live Weight (kg)	Stocking Rate (cows/ha)	Fixed Price—Unlimited Market	Fixed Price—Unlimited Market Discounted 10%	Variable Price—Finite Market	Variable Price—Finite Market Discounted 10%
0 (2017)	4284	206.3	167.4	204.1	464.4	2.465	0	0	0	0
1 (2018)	4312	208.1	169.2	205.4	465.0	2.454	74.2	67.5	50.8	46.2
2 (2019)	4341	209.9	171.1	206.8	465.5	2.443	148.2	122.5	110.8	83.3
3 (2020)	4370	211.6	172.9	208.1	466.0	2.433	221.8	166.7	149.9	112.3
4 (2021)	4399	213.4	174.8	209.5	466.5	2.422	294.3	201.0	198.6	135.6
5 (2022)	4428	215.2	176.6	210.8	467.0	2.412	366.0	227.4	246.6	153.1
6 (2023)	4456	217.0	178.5	212.2	467.6	2.401	437.5	246.9	293.9	165.9
7 (2024)	4485	218.7	180.4	213.5	468.1	2.391	508.2	260.8	340.5	174.7
8 (2025)	4514	220.5	182.2	214.9	468.6	2.380	578.3	269.8	386.3	180.2
9 (2026)	4543	222.3	184.1	216.2	469.1	2.370	647.6	274.6	431.7	183.1
10 (2027)	4572	224.0	186.0	217.6	469.6	2.360	716.2	276.1	476.8	183.8
Total							3992.3	2113.3	2685.9	1418.2
Benefit/farm							0.346	0.183	0.234	0.123

The increases in cow productivity and small increases in live weight caused increases in requirements for metabolizable energy and because a constant feed supply was imposed, the stocking rate declined from 2.465 to 2.360 cow/ha over 10 years.

Table 4 also show the discounted (at a rate of 10% annually) and undiscounted industry benefit for the scenarios simulated; namely, a limited and an unlimited market for the sale of dairy products, with corresponding fixed and variables prices of dairy products. When

the market for dairy products was unlimited and prices of dairy products were constant regardless of total supply of dairy products, the 10-year undiscounted aggregated enterprise benefit was NZD 3999.3 million representing NZD 346,000 per farm. The corresponding farm benefit with a 10% discount rate was reduced to NZD 183,000/farm. Assuming a limited market for dairy products with prices of dairy products determined by the amount of dairy products supplied into the market, the 10-year undiscounted aggregate benefit was NZD 2685.9 million representing NZD 234,000/farm. The corresponding figures for the 10% discounted values were reduced to NZD 1418 million of industry benefit and NZD 123,000/farm, which was about 50% of the undiscounted benefit.

The increments in undiscounted industry benefits for the two market scenarios simulated are presented in Figure 2a.
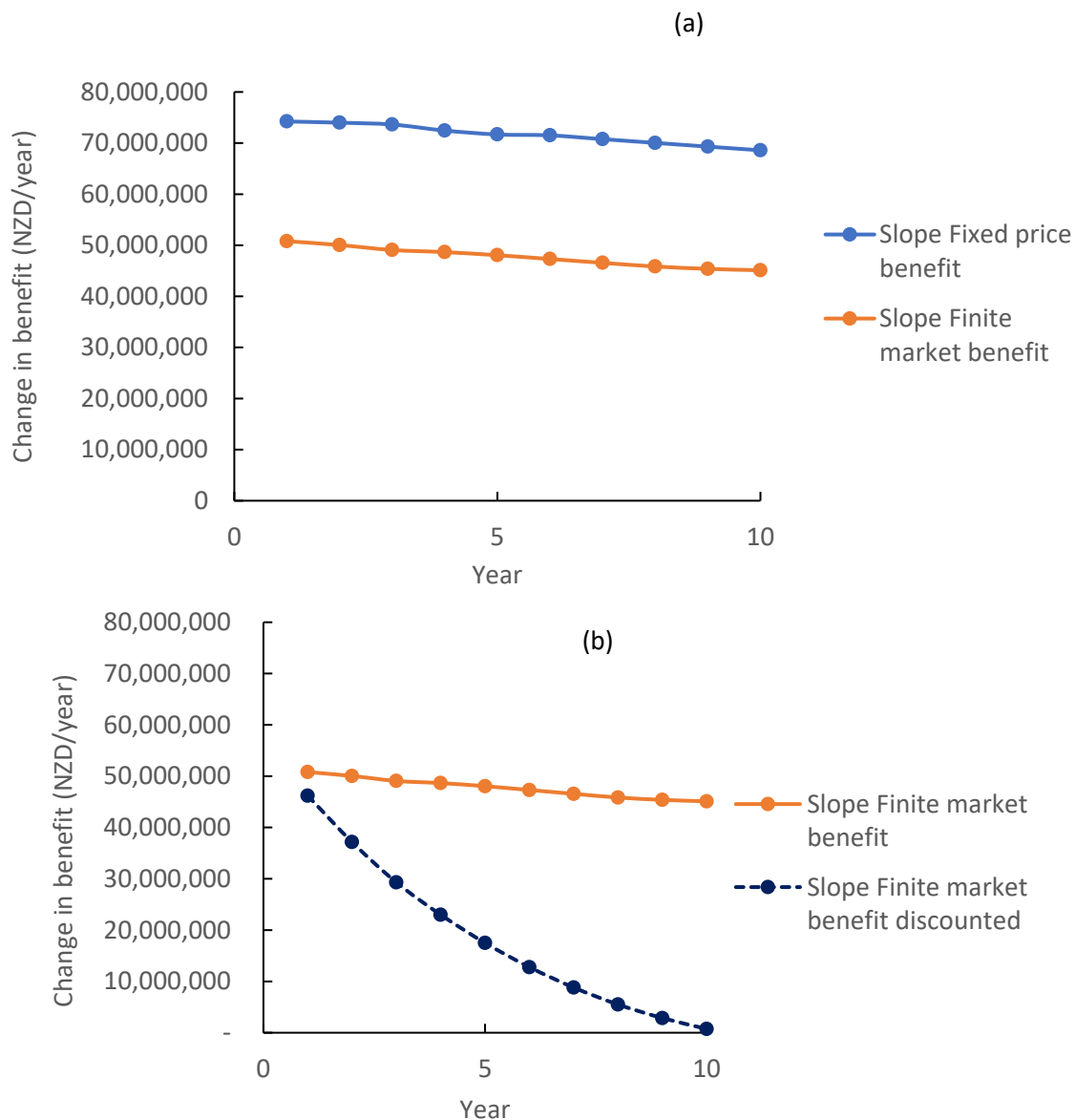

Figure 2. Development of the annual industry benefit (panel **a**) and discounted annual benefit (panel **b**) from genetic gains for lactation yields of milk, fat and protein and cow live weight over 10 years.

Figure 2b shows that when the market was represented by a more realistic model of prices being quantity sensitive, the overall benefit of the genetic gains was reduced by about 30%, compared to the fixed price, or infinite market, assumption.

The effect of the amount of dairy products supplied into the market on the price of dairy products is shown in Table 5; as production increased, the market prices inevitably declined.

Table 5. Production and price of dairy products in the base year and after 10 years of genetic improvement for milk, fat and protein.

Dairy Product [1]	Year 0		Year 10	
Commodity	Price (USD/ton)	Production (ton/year)	Price (USD/ton)	Production (ton/year)
AMF	5174	212,020	5036	228,519
Specialty fat	8000	50,000	8000	50,000
Butter	4273	270,000	4273	270,000
Specialty cheese	5000	5000	5000	5000
Cheese Cheddar	4293	280,000	4225	290,000
WMP	3059	680,000	2999	720,000
SMP	2876	239,251	2816	250,000
Casein lactic	6059	220,000	5850	239,734
WPC Cheese	5797	19,139	5794	19,811
WPC Lactic	5105	57,245	5080	62,380
BMP	2748	72,640	2715	76,612
Infant formula	8900	92,000	8900	92,000

[1] AMF = anhydrous milk fat, WMP = whole milk powder, SMP = skim milk powder, WPC = whey protein concentrate, BMP = butter milk powder.

Figure 3 shows the volatility in dairy commodity prices over the decade of the modelling. The prices used in the model were consistent with prices for the commodities over the decade.

Figure 3. Overall price index over past 10 years (source: Global Dairy Trade).

4. Discussion

A national benefit of NZD 346,000 per farm over a decade was expected to arise from the current genetic trends for lactation yield of milk, fat and protein and live weight assumed in this simulation under the whole of enterprise market model if all dairy products were sold at the same price every year. This scenario was unrealistic because prices of dairy products fluctuate drastically during the year and through the years as supply and demand vary (Figure 3). The objective of this study was to estimate the value of genetic improvement for milk production evaluated using a whole of enterprise market model into which the products were sold into economically more realistic volume sensitive markets as commodities.

When prices of dairy products were subjected to supply curves determined by a finite market for dairy products, the national benefit was reduced from NZD 346,000 to NZD 234,000 per farm over a decade. This analysis was based on the counterfactual of the status quo in herd performance being maintained i.e., no genetic improvement. Although this seems unrealistic, there has been a selective breeding (herd improvement) programme operating in New Zealand for many decades. Nevertheless, historically, the estimated value of breeding improvements has been based on a similar status quo counterfactual. Although the benefit was non-trivial, this model demonstrated that there were three forces at play that serve to erode some of the gains from continued genetic improvement of the herd that resulted from the progressive increase in production per cow.

4.1. Factors Impacting Genetic Improvement

Firstly, as the productivity of the herd improved given a fixed feed supply, the stocking rate declined to maintain the herd's energy balance. Table 4 shows the gradual decline in the stocking rate. Consequently, overall cow numbers declined progressively as a result. In passing, it is noted that this decline was probably beneficial from a methane emissions perspective, although the decline was unlikely to be proportional to the reduction in number of cows, because the same amount of feed was being consumed. More data are required to establish this trade-off.

Secondly, the increase in overall milk production caused a progressive decline in market prices as the markets adjusted to the increase in the supply of the various dairy commodities. This effect was demonstrated in more detail in Table 5, where the prices and quantities for the initial year and after a decade of herd improvement were compared.

Thirdly, as the flow of benefits emerge in the future, such future benefits needed to be discounted to properly count them on a common timeframe. To achieve this, a discount rate of 10%/year was used as suggested by Sheppard and Malcolm [6]. Table 4 compares the raw benefit and the discounted benefit series.

Although the industry model considered in detail the finiteness (non-linearity) of the markets and rigorous optimization of product choices, and stocking rate changes over the industry, there were still significant limitations. Current selection indexes also include many other traits, namely, fertility, somatic cell count, survival, body condition score, calving difficulty, gestation length and udder conformation traits [23]. The economic impact of these traits was ignored in the model. However, these non-production traits ultimately determine the life expectancy of the average cow and cause changes to the age structure of the herd. Our model would be able to evaluate the effect of longevity on the industry benefit and farm profit. Longevity and milk yield have inversely changed over recent decades. Length of productive life has decreased [24], with a decrease range between 0.9 to 3.04 years for most top high milk producing countries, while milk yield has increased over the same period in a range between 18.5 to 129.7 kg per animal per year [25]. This would be a fourth impediment that would reduce the economic value of future genetic gain, assuming the direction was toward greater cow milk or milk solids yield because the need for more replacements consumes metabolizable energy that would otherwise be directed to milk production together with additional calf rearing costs. Further analysis based on reliable local data is needed to quantify this impact.

4.2. Quantifying Herd Improvement

Many attempts have been made to estimate breeding benefits in the dairy industry. Gibson [26] laid down some useful guidelines: all costs (farm, processing and marketing) need to be taken into account, and milk payment systems can be unreliable because value streams e.g., lactose can be arbitrarily allocated between fat, protein etc., changes in outputs needed to be properly accounted for, and enterprise rescaling would need to be taken into account if the feed requirement changed. These concerns have been addressed in the current model. The model included all costs in the farm-processing system for the entire enterprise. The arbitrariness of the payment system for the milk produced was

avoided by the use of a market model for the outputs where prices adjusted in accordance with the changes to output; thereby avoiding average prices i.e., infinite markets. By using a market model with dynamic pricing, the markets were treated as finite with the varying prices reflecting consumer preferences. The rescaling aspect is dealt with in the model by imposing a rigorous metabolizable energy balance on the herd. Consequently, as the productivity of the animals increased, the stocking rate adjusted accordingly (along with herd costs), so that additional production cannot emerge without the requisite food supply. Lopez-Villalobos et al. [10] took a 25-year view of the New Zealand dairy industry to analyze which breed of cow was the most economic for the industry. In their study, a variety of dairy commodities were considered using fixed market prices—essentially infinite markets. The current model has avoided this limitation.

4.3. Herd Improvement as a Function of Economic Efficiency

Groen [8] went further and suggested that the purpose of genetic improvement involved improving the economic efficiency of the enterprise (rather than production, or output). When viewed through this lens, the results have some interesting implications. Examination of the benefit series (Table 4) revealed that while the benefit was increasing with time, the slope progressively declined (Figure 2a), which suggested that a maximum will be reached eventually and then the benefits would decline. With the values used in this model, the maximum benefit would be at least a century away before the decline sets in. However, the negative slope had a greater concern when the future benefits were discounted. With the parameters used, Figure 2b shows that the discounted annual benefit reached a maximum at year 10 and then began its progressive decline towards zero. This suggested that a programme of genetic improvement was not an unlimited road to prosperity. Rather, it was revealed as being a finite and time-bound process. It is noted in passing, that quantitative genetic improvements schemes have been widely adopted for 70 years or more, suggesting that at least some aspects of efficiency improvement have been achieved and are now no longer available. Although this aspect has not been previously documented in dairy cattle breeding, this finding was not entirely unexpected from an economic perspective. Indeed, modern farming systems are highly efficient operations. Consequently, the model reveals that there is only a finite amount of inefficiency in the system that the herd improvement programme was able to address. This paradigm was discussed some years ago regarding formulation of breeding objectives for the poultry industry. Shultz [27] indicated that "the economic values are non-linear (stairstep pattern) for most of the critical traits. The economic value of a trait (and the saleability of his stock) is determined by the performance of his stock relative to the competition. The point at which there is a substantial change in the economic value was referred to as a "breakpoint". If his stock is at the bottom of the breakpoint for a critical trait, he must quickly improve the trait or he will soon be out of business. If the trait is at the top of the breakpoint with a reasonable margin for error, selection pressure used to further improve the trait will be wasted".

4.4. Wider Efficiency Considerations

Factors that would undermine this efficiency objective would be major changes in market conditions such as consumer preferences, the opening up of new markets (e.g., China), changes to production subsidies in competing markets, environmental constraints (especially on land use, fertilizer usage, water availability, greenhouse gas emissions) or major changes to the cost structures of dairy farms (e.g., automation). In these situations, the breeding objective would need revision and a new direction implemented. However, the aggregate price trends over the past decade shown in Figure 3 suggested that overall consumer demand lacked an obvious trend, despite considerable volatility. But the prospects for the next few decades appear rather different from the past few decades.

4.5. Economic Benefit of Breeding Depending on Scale

Sheppard and Malcolm [6] examined the profitability attributable to genetic improvement of dairy herds in Australia at the farm-scale level. They found that the benefits of genetic improvement tended to be less than what analysis of improvement might deliver when evaluated at the individual cow level. They indicated that the reduction in profit at the farm level was in part associated with farm managers being unable to accurately adjust the stocking rate for the new production conditions i.e., deliver optimal nutrition and allow for the impact on herd health (declining life expectancy). An inability for farm management to upgrade to the more sophisticated (finely tuned) production conditions was also suggested as a factor. Even though the current model did not consider these factors, widening the scope of the focus from the farm to the whole enterprise and recognizing the limitations of the market, resulted in an erosion of the benefits of genetic gain. Sheppard and Malcolm [6] also emphasized the importance of considering all options to invest to raise profitability, rather than focusing excessively on genetic improvement. These observations are endorsed.

4.6. Implications for the Future

The model in this work still has limitations. Extensions to include the environmental footprint of the industry in detail would be desirable. Such a model would need to consider the emission of greenhouse gases and the handling of water resources. However, and despite the need, in New Zealand there are currently no clear directions on emissions pricing (or limits). These gaps, and the use of supplementary feed (including the importation of about 2,000,000 t/a of palm kernel expeller) may also have a significant environmental impact that is currently inadequately accounted for in any models that have been reported. Declining life expectancy of animals in the herd [26] suggests further work is required to quantitatively examine this trend. All this needs to be focused towards understanding the optimal efficiency of the animals required to be produced by the breeding program.

5. Conclusions

A whole of market model was used to estimate the financial benefits to dairy farmers if the rate of herd genetic improvement continued as suggested by the trend from 2014 to 2018 in the New Zealand dairy industry. On an undiscounted basis, this benefit was estimated to be NZD 234,000 per herd, compared with the discounted (10%) value of NZD 123,000 per herd. The model suggested that the finite market assumption resulted in a reduction of the breeding benefit by about a third, compared with infinite market case. On a whole of enterprise basis with finite markets, the results revealed that genetic gain in a specified direction is a time-bound process and the gains are necessarily capped to a finite limit.

Author Contributions: N.L.-V. developed the farm-animal model. P.W. developed the post farmgate industry-wide processing model and the associated linear optimization routine using What'sBest. N.L.-V. conceptualized the need to examine the effect of persistent breeding gains at the industry level. P.W. conducted the simulations and found the key results. G.U. gave advice on the international market for dairy products and goals of the herd improvement programme. P.W. prepared the draft manuscript and this was scrutinized by N.L.-V. for the purposes of possible publication. All authors have read and agreed to the published version of the manuscript.

Institutional Review Board Statement: Not applicable for studies not involving humans or animals.

Informed Consent Statement: Not applicable for a study involving economic models.

Data Availability Statement: The primary data are referenced. The analysis is based on theoretical mathematical models developed in Excel and solved for using What'sBest.
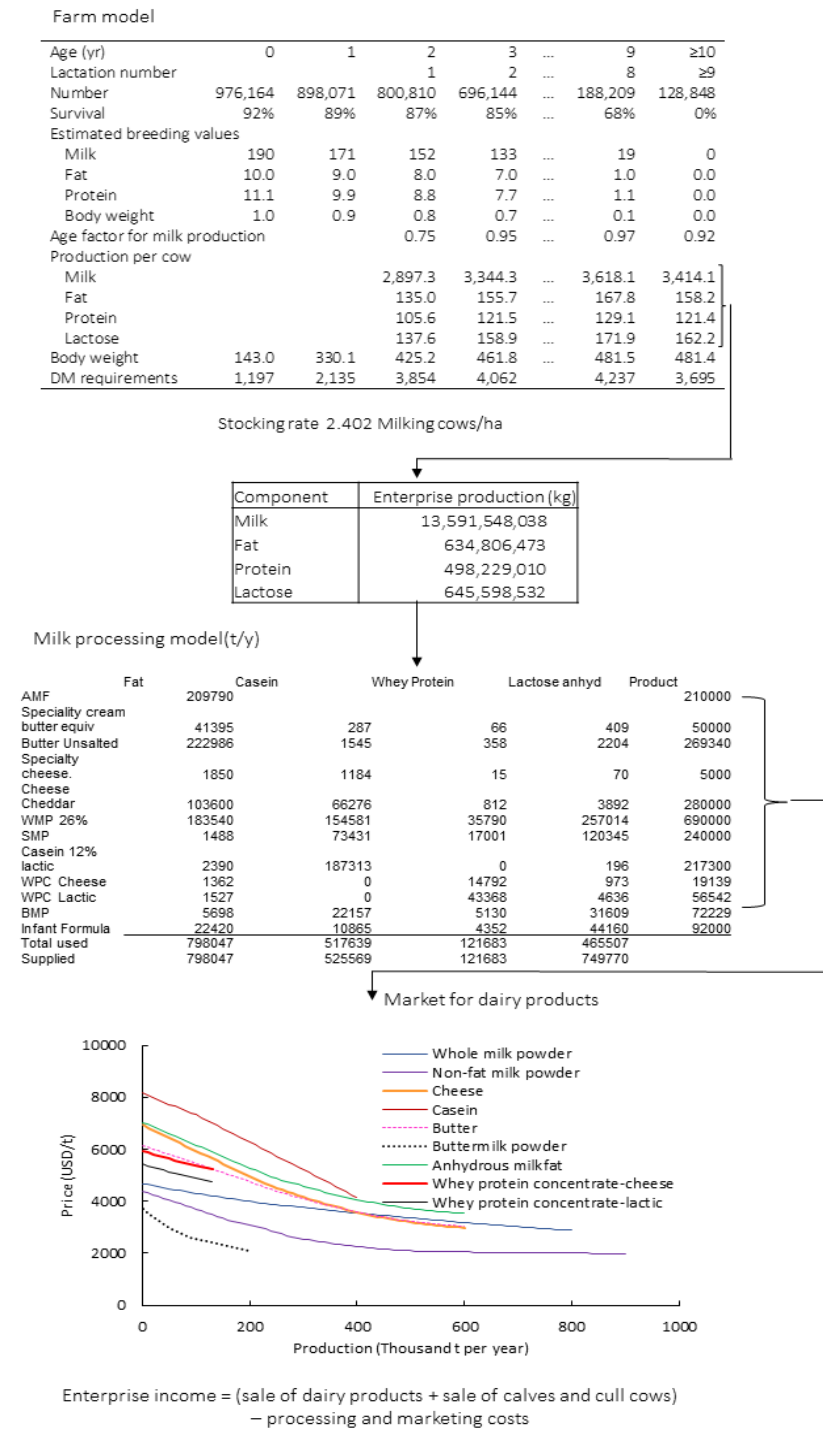
Appendix A

Figure A1. Representation of the whole of enterprise market model showing the integration of farm, milk processing, and market models.

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